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DETECTION OF INTERPLANETARY ELECTRONS FROM 18 keV TO 1.8 MeV DURING SOLAR QUIET TIMES

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ON THE ORIGIN OF 200 keV INTERPLANETARY ELECTRONS

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GSFC

GODDARD SPACE FLIGHT CENTER
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TABLE OF CONTENTS

I. DETECTION OF INTERPLANETARY ELECTRONS FROM 18 keV TO 1.8 MeV DURING SOLAR QUIET TIMES

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II. ON THE ORIGIN OF 200 KeV INTERPLANETARY ELECTRONS

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DETECTION OF INTERPLANETARY ELECTRONS FROM 18 KEV TO 1.8 MEV DURING SOLAR QUIET TIMES

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ABSTRACT

A quiet-time component of interplanetary electrons having energies above solar wind energies and below those characterized as cosmic radiation is observed. Its energy spectrum generally falls with energy from 18 keV to 1.8 MeV, but shows a feature in the 100-300 keV range. The observed temporal variations of the intensity suggest that the 18-100 keV portion is solar and the 0.3 - 1.8 MeV portion is galactic in origin. Solar and terrestrial neutron-decay electrons appear inadequate to explain the 100-300 keV feature.

In this letter we report the first observations of a quiet-time interplanetary electron component covering the energy range from 18 keV up to the previously reported cosmic ray electron measurements above 2 MeV. With these observations the entire quiescent interplanetary electron spectrum from thermal energies to 10^{12} eV has now been measured. The intensity of these quiet-time electrons is 3 to 5 orders of magnitudes below previously measured intensities in this energy region observed during times of enhanced interplanetary activity. The features of this quiet-time component include (a) a power-law energy spectrum $\frac{dJ}{dE} = A\ E^{-\gamma}$ with index γ 2.3 between 18 and 100 keV at quietest times; (b) a spectral feature in the 100-300 keV region that may possibly be due to a neutron decay component; (c) another power-law spectrum with index $\gamma = 3.2$ between 0.3 and 1.8 MeV; (d) temporal variations of a factor of 3 or more for the 18-100 keV electron intensity over time periods of several days and essentially no temporal variations of the component above 100 keV.

INSTRUMENTATION

The measurements come from two independent experiments carried on the NASA IMP-6 spacecraft. This scientific satellite was launched into a high apogee equatorial orbit from Cape Kennedy on March 13, 1971. Initial orbit parameters are: apogee, 211, 251 km; perigee, 6, 729 km; sun-earth-apogee angle projected on the ecliptic plane, 14.8°. All the observations reported here are from times when the spacecraft was well outside the earth's magnetosphere.

Electron spectrum measurements from the University of California experiment come from a passively cooled ($\leqslant -55^{\circ}C$) solid state detector telescope which is open to space without any foil covering. The telescope, shown in Figure 1a, consists of three elements. The first measures the energy of stopping particles and the third provides anticoincidence against penetrating particles. Electrons from 18 keV to ~500 keV are measured. To take advantage of the high inherent energy resolution ($\leqslant$8 keV fwhm) of the cooled surface barrier detectors, the output below 500 keV is pulse height analyzed into 64 channels by use of a computer aboard the spacecraft. The IMP-6 UCal detector is not capable of unambiguously separating electron fluxes from proton fluxes below 200 keV in energy. However observations from the Apollo 15 Particles and Fields Subsatellite, which can separate proton and electron fluxes, show that at quiet times the electron flux dominates the proton flux by about a factor of ten in the energy range below 200 keV.[1,2] Background due to cosmic ray nucleons penetrating the front detectors without triggering the back anticoincidence detector has been computed and subtracted from the observed fluxes. These corrections are negligible below 100 keV. Calibration of the system is provided by electronically switching the gain of the detector system down by a fixed factor in order to view an on-board radioactive source. Confirmation of the calibration is obtained from the cutoff energy for electrons entering the anticoincidence detector, which depends only on the detector thickness.

The Goddard Space Flight Center (GSFC) detector (Figure 1b) incorporates a stilbene crystal, with a CsI (Tl) anticoincidence, in which stopping particles have both their energy loss and rate of ionization measured by observing the pulse height and pulse shape. In-flight measurements indicate complete proton vs. electron separation for all electron energies above 50 keV. The pulse decay in CsI (Tl) is more than an order of magnitude slower than either lightly or heavily ionizing particles in stilbene, so that it was possible to view the entire arrangement with one photomultiplier tube. A second photomultiplier tube with a large CsI (Tl) crystal was incorporated in a priority-coincidence system, in order to determine the positron to electron ratio as a function of energy, by observing the incidence of annihilation radiation accompanying stopped electrons. This measurement requires a greatly improved statistical study and its results will be reported at a later time. Another phototube views a separate stilbene crystal system, symmetrically placed with respect to the gamma-ray spectrometer but closed off with anticoincidence scintillator. This is used to evaluate the local or spacecraft-induced background of secondary gamma rays and cascade showers that produce Compton electrons, and thus distort the observed spectrum of primary interplanetary electrons. This background was found to be small compared to the observed quiet time spectrum. The proper operation of the system was further tested by studying the characteristics of electron and proton events from several solar flares which occurred in early and mid-1971. The electron measurements were calibrated by the use of radioactive sources before launch, and were corrected for background events observed in the ionization versus energy plots of data taken outside the magnetosphere. The resulting spectrum of quiet-time electrons is believed to contain systematic errors which do not exceed 25 to 30 percent. These errors and the statistical errors are included in the GSFC points of Figure 2.

OBSERVATIONS

The electron spectra from both experiments are shown in Figure 2. The observations are taken at the quietest time during several months observing period. This low intensity level has been observed on several occasions of a few days duration. Large temporal variations of the fluxes below 100 keV occur over a time scale of several days. At more disturbed times the flux below 100 keV can be a factor of 3 or more above the quietest levels, even when all solar flare particle events have been eliminated from the data. At energies above 100 keV the fluxes do not vary substantially (≤25% over several months) in the absence of solar events. The excellent agreement of the fluxes measured by the GSFC and the IMP-6 UCal experiments below 500 keV should be noted. From 0.3 to 1.8 MeV the spectrum fits a power law, $\frac{dJ}{dE} = 1.55 \times 10^{5} E^{-3.2}$ $(\mathrm{cm}^2 \text{ ster sec keV})^{-1}$ where E is in keV. Between 18 and 100 keV the spectrum at the quietest times is $\frac{dJ}{dE} = 3 \times 10^2 \ E^{-2.3}$ (cm^2 sec ster keV)$^{-1}$. Each experiment independently observed a feature in the 100 to 300 keV region which prevented the description of the spectrum terms of a single power law. Since the evidence for this feature is in surprisingly good mutual agreement, we view the possibility that it is due to systematic errors in detector calibration as highly unlikely. Furthermore, this structure, if viewed as a bump superimposed on a smooth spectrum, appears at an appropriate energy interval for neutron-decay electrons. The beta-decay spectrum expected for decay of neutrons at rest peaks at about 280 keV and ends at about 783 keV. The observed spectrum both peaks and disappears into the continuum at somewhat lower energies but nonetheless is qualitatively suggestive of a neutron decay component.

The interplanetary quiet-time electron spectrum over all available energies is compiled in Figure 3. Solar wind electron data merging into the theoretical 1.5×10^5 °K Maxwellian (dashed line) are shown in the 10 to 300 eV region as solid dots[3] and similar but more recent data up to 1 keV as open dots.[4] In the energy range 0.5 keV to 15 keV the data shown are from the Apollo 15 Subsatellite.[1,2] These data are not strictly quiet time as indicated by the measurements above 20 keV (diamonds) taken in the same period. In the 18 keV to 1.8 MeV energy-region, the results presented in this letter are the only known quiet-time data, except for two points in the several hundred keV region[5] which are a decade lower in intensity. We note that the value of the positron to electron ratio in this energy range using the Cline and Hones[6] values for the positron intensity, is $\frac{e^+}{e^- + e^+} \approx 20\%$ for the flux levels reported here, compared to $\sim 100\%$ for the values reported in reference 5.

At the high energy end the reported spectrum joins smoothly onto the OGO-5 and IMP-4 spectra, shown here as squares and crosses, respectively, in the 2 to 20 MeV region.[7,8] A compilation of a variety of high-energy electron data are shown in the 20 MeV to 1 TeV region in order to provide a complete picture of the known cosmic-ray component.

DISCUSSION

The previously reported cosmic ray spectrum in the range 2-20 MeV fit a power law spectrum with index 1.75, substantially different from the 3.2 measured here for electrons from 0.3 to 1.8 MeV. The lack of temporal variations in the 0.3-1.8 MeV intensity over the first few months of observation is evidence against a solar origin for these electrons. As shown in a review of over half a solar cycle of 2-20 MeV electron observations[9] it is possible to go through several months with no time variations, such as in mid-1968, as contrasted with large variations of a factor of ≈ 5, as in late 1967. Only a thorough and detailed study of the time variations of the 0.3 to 1.8 MeV component over a protracted period will show whether its behavior is like that of the >2 MeV component. At present, the absence of observed time variations is consistent with a cosmic-ray identification of the 0.3 to 1.8 MeV component although the marked change in spectral index from that for the 2-20 MeV component suggests that a different galactic origin or different form of modulation may be involved.

By the same argument, the presence of temporal variations in the electron fluxes between 18 and 100 keV indicate that these fluxes are most likely of solar origin. Anderson et al.,[1] find that this component extends to energies of $\leqslant 5$ keV with a smooth steepening of the spectrum to $\gamma \approx 3.5$

at low energies. Below ~2 keV the character of the electron flux changes abruptly, both steepening in spectral slope to $\gamma \gtrsim 5$ and changing in angular distribution from essentially isotropic to highly anisotropic. Apparently these fluxes are part of the solar wind plasma electron component. The fluxes from 5-100 keV may be an extension of the solar wind to higher energies,[10] or they may be a separate component related to solar active regions and storms of solar radio bursts at the sun.[11] The relationship of the solar wind plasma to active regions on the sun is not clear at present. Further studies of the temporal variations of the 5-100 keV electron component are needed to clarify its origin.

The spectral feature between 100 and 300 keV presents the most puzzling aspect of the results reported here. The degree of anisotropy of the electron intensity in the 100 to 300 keV region is small, with an upper limit of ≈2 percent. If these were solar or terrestrial neutron-decay electrons, they are subject to a sufficient degree of diffusion to randomize their trajectories. The total area under the bump in the spectrum, over and above the continuum component, is about 0.8 electron cm^{-2} sec^{-1} $ster^{-1}$. Using the spectrum for cosmic ray neutron leakage flux at the top of the earth's atmosphere given by Lingenfelter[12] we have calculated the rate of production of electrons from the decay of these neutrons outside the earth's magnetosphere as a function of distance. The total integrated neutron-decay electron production from this source is $\frac{dn}{dt} \leqslant 10^{-15}$ $(cm^3\ sec)^{-1}$ at 16 earth radii (R_E) and $\leqslant 0.5 \times 10^{-15}$ $(cm^3 sec)^{-1}$ at 32 R_E distance from the earth. Essentially all of the electrons come from decay of <1 MeV energy neutrons. An absolute upper limit to the lifetime of these electrons near the earth is the time it takes the solar wind to convect these electrons out of the region near the earth where they are produced. If the propagation of the electrons is dominated by diffusion as appears likely from studies of impulsive solar electron events, then the electrons will escape much more rapidly. The effective scale size of the neutron-decay region is certainly $<100\ R_E$ so the maximum lifetime is $\tau_{max} \leqslant \frac{100\ R_E}{V_{SW}} \approx 2 \times 10^3$ sec., where V_{SW} = solar wind velocity is taken as 320 km sec $^{-1}$.

The maximum possible density of terrestrial neutron-decay electron is then $n \approx \tau_{max} \frac{dn}{dt} \leqslant 2 \times 10^{-12}\ cm^{-3}$, and the maximum possible flux $J = \frac{nv}{4\pi} \leqslant 4 \times 10^{-3}\ (cm^2\ sec.\ ster.)^{-1}$. This is more than two orders of magnitude below the observed excess flux of 0.8 $(cm^2\ sec\ ster)^{-1}$, so that a terrestrial neutron-decay origin for these electrons can be ruled out.

Assuming a solar origin for these electrons, i.e. as the decay of low energy neutrons near the sun, we can deduce an upper limit to the outward solar low energy neutron flux. From studies of impulsive solar electron events it is clear that the propagation of these electrons is dominated by diffusion rather than convection at these energies, with diffusion coefficients of $K \approx 10^{22}\ cm^2\ sec^{-1}$. For continuous emission from the sun the steady state equation for the particle density n becomes[13] $K \frac{dn}{dr} = \frac{\Phi}{4\pi r^2}$, where Φ = total rate of emission by the sun, and r = distance, and K the diffusion coefficient. If we take $K = K_o r$ then the solution is $n = \frac{\Phi}{8\pi K_o r^2}$. Putting $K = 10^{22}\ cm^2\ sec^{-1}$ at 1 A.U. and using $J = \frac{nv}{4\pi} = 0.8\ (cm^2\ sec\ ster)^{-1}$ we obtain $\Phi = 2 \times 10^{27}$ neutrons sec $^{-1}$ as the rate of emission of neutron-decay electrons from the whole sun.[14] This compares with an upper limit of 6×10^{24} neutrons sec $^{-1}$ calculated by Ramaty, Cline and Fisk,[15] who extrapolated down in energy from upper limits to the 20-200 MeV neutron flux observed at 1 A.U.

An alternative possibility is that the 100-300 keV electrons enter the solar system from the nearby galactic medium. The lack of temporal variations over the first few months of data for the 100-300 keV electrons is consistent with the behavior of the 0.3-1.8 MeV and 2-20 MeV components which are presumably galactic in origin.

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[15] Ramaty, R., T.L. Cline, and L. Fisk, in preparation (1972)

Figure Captions

Figure 1a. The low-energy electron detector.

Figure 1b. The high-energy electron detector to the same scale.

Figure 2. Quiet-time interplanetary electron spectra from the two experiments on the IMP-6 satellite.

Figure 3. A compilation of quiet-time interplanetary electron data, including various solar wind and cosmic ray results. The data in the 1 to 15 keV range are from Apollo 15 Subsatellite [2] and are not from a completely quiet period; the intensities in the 20-100 keV region (diamonds) appear to be enhanced by a factor of 3 or more.

9 June 1972

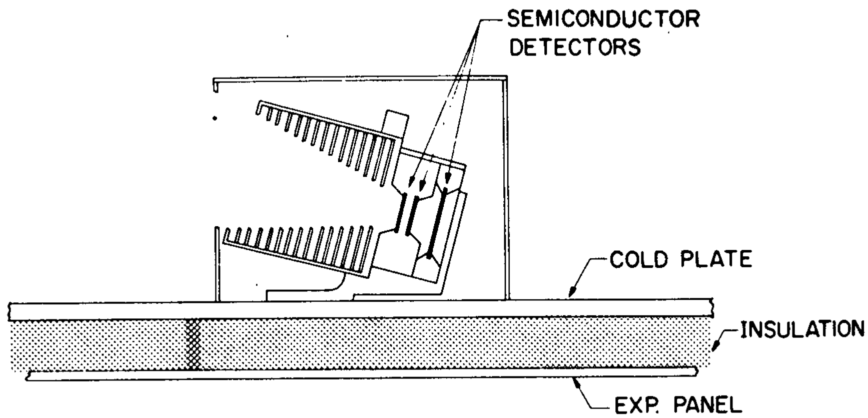

Figure 1a

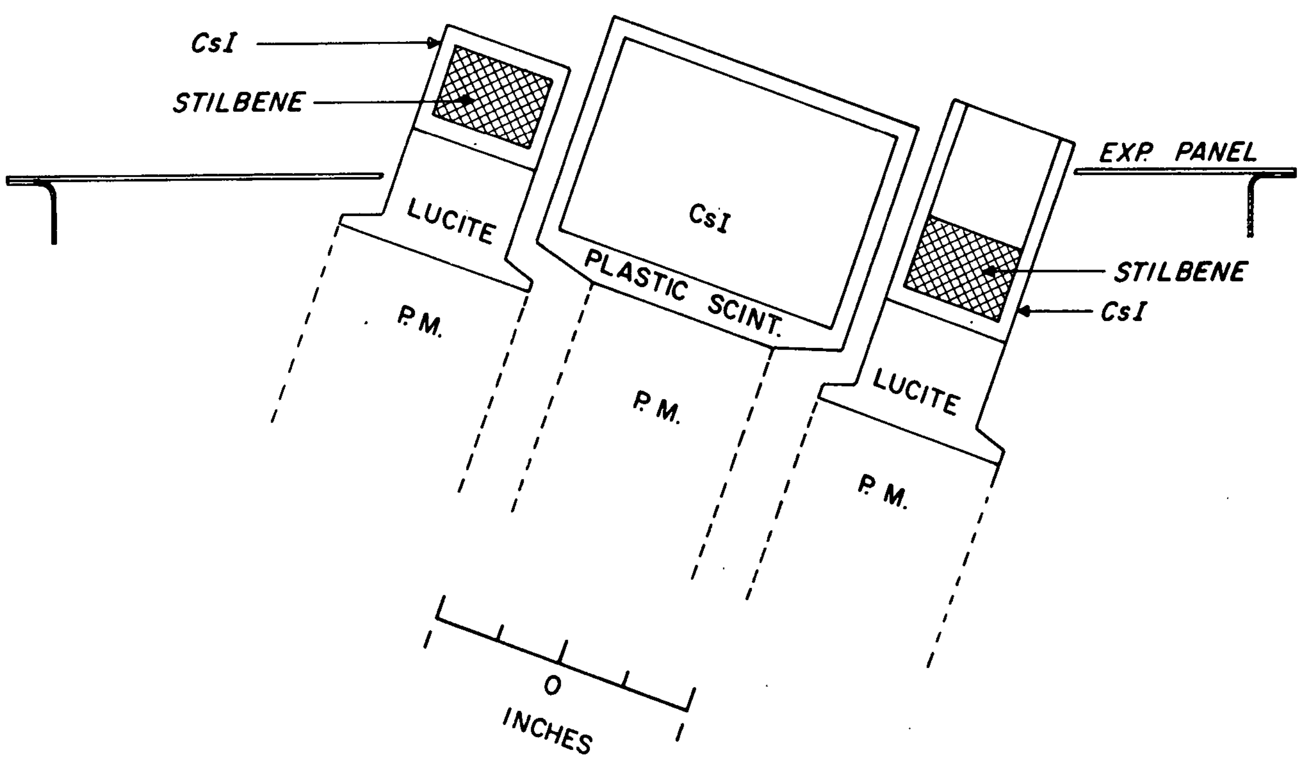

Figure 1b

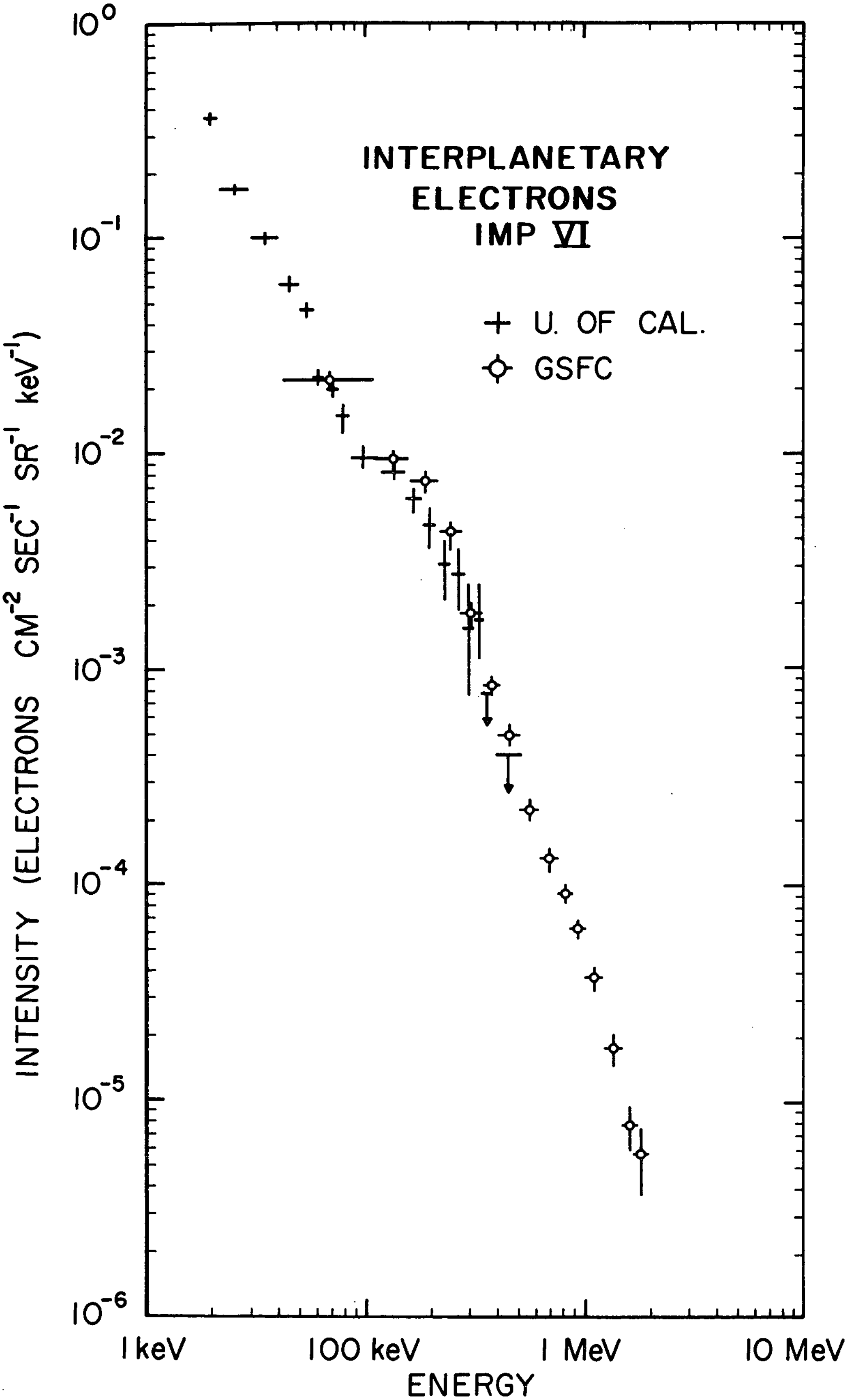
INTERPLANETARY
ELECTRONS
IMP VI
U. OF CAL.
GSFC
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
INTENSITY (ELECTRONS CM^{-2} SEC^{-1} SR^{-1} keV^{-1})
1 keV
100 keV
1 MeV
10 MeV
ENERGY

Figure 2

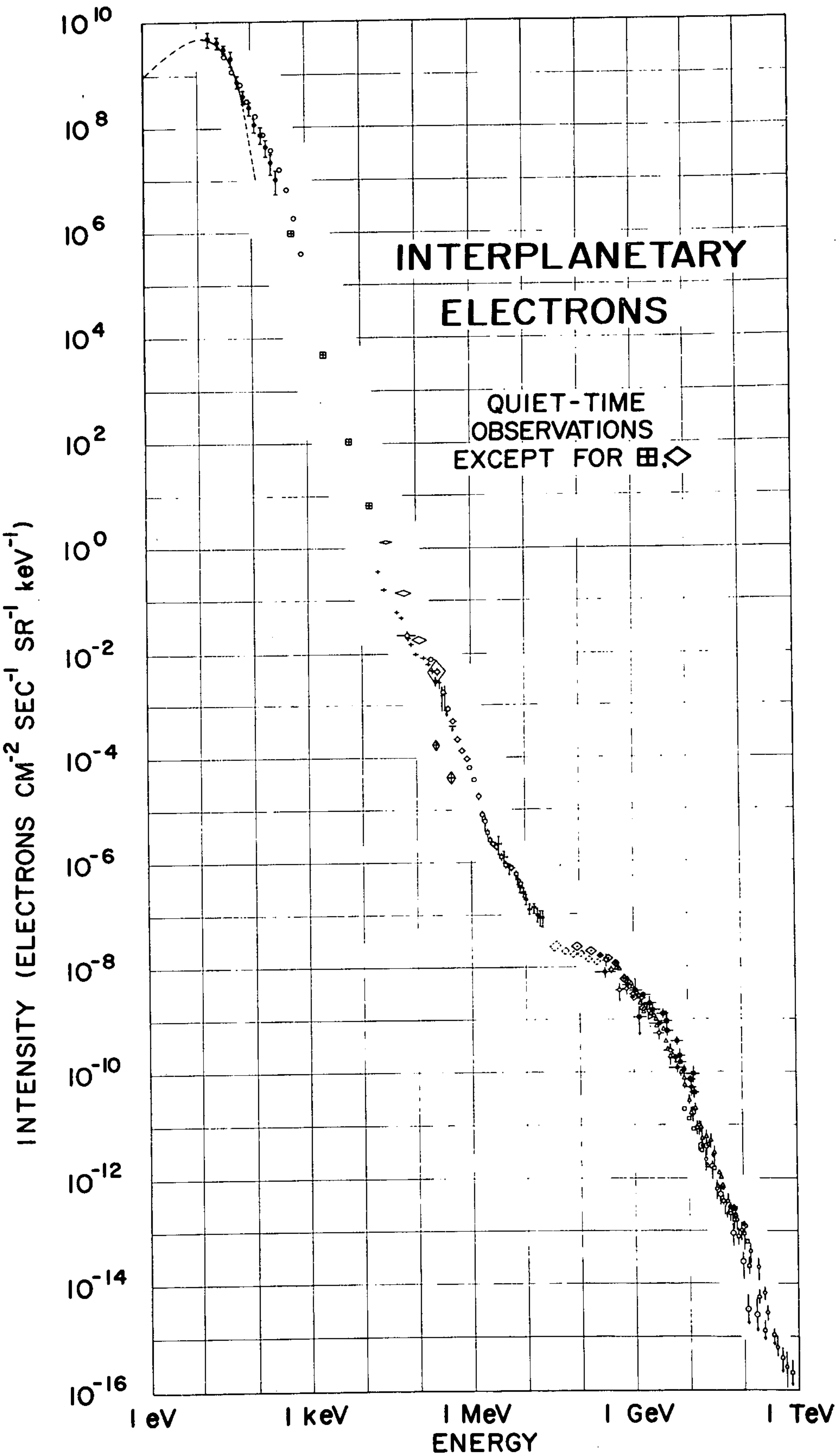
INTERPLANETARY ELECTRONS
QUIET-TIME OBSERVATIONS EXCEPT FOR ⊞, ◇
INTENSITY (ELECTRONS CM^{-2} SEC^{-1} SR^{-1} keV^{-1})
10^{10}
10^{8}
10^{6}
10^{4}
10^{2}
10^{0}
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
10^{-16}
I eV
I keV
I MeV
I GeV
I TeV
ENERGY

Figure 3

ON THE ORIGIN OF 200 KEV INTERPLANETARY ELECTRONS

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A spectral feature at ~ 200 keV in the recently observed intensity of interplanetary electrons is examined as to its possible solar, interplanetary or galactic origin.

Lin et al.[1] have reported the first quiet-time observations of the interplanetary electron spectrum covering the range 20 keV to 2 MeV. Their results consist of two independent measurements which overlap in the 50 to 400 keV region, both of which indicate the existence of a distinct spectral feature at about 200 keV. If this feature is interpreted as a bump or excess above a power-law background, it consists of about 0.8 electrons $cm^{-2}sec^{-1}sr^{-1}$ over and above the continuum component. It may instead be considered as a shelf or cut-off between two approximate power laws. In the present Letter we examine the suggestion[1] that this spectral feature could be due to a neutron-decay electron component of either solar or galactic origin, and we also consider alternative source models, including production by nearby galactic objects or acceleration at the outer boundary of the solar system.

We consider first the question of neutron production. Earth-albedo neutrons have been shown[1] to be inadequate to account for the electron excess by more than a factor of 100. If the ~ 200 keV electrons result from the decay of solar neutrons and if these electrons diffuse from the sun to earth, Lin et al.[1] estimate that the necessary neutron source at the sun is about 2×10^{27} neutrons/sec. These neutrons cannot result from thermonuclear reactions in the solar corona, since as estimated by Audouze[2] this mechanism produces less than $\sim 2 \times 10^{-24}$ neutrons $cm^{-3}sec^{-1}$, a value which leads to a negligible total neutron yield for any assumed production volume at the sun. The most likely source of solar neutrons would instead be high-energy nuclear reactions of energetic protons, alpha particles and CNO nuclei with the ambient hydrogen, helium and CNO in the solar atmosphere. The production of neutrons in solar flares by these processes has been considered in detail[3]. Using the techniques of reference 3, we have calculated the quiet-time production of neutrons at the sun, and we have compared the resultant steady state neutron flux at earth with a new upper limit on high-energy solar neutrons[4]. According to this measurement, the background neutron flux is $\sim 10^{-3}$ neutrons $cm^{-2}sec^{-1}$ and the upper limit on solar neutrons is $\sim 3 \times 10^{-4}$ neutrons $cm^{-2}sec^{-1}$ (Leavitt, private communication). We summarize our results in Table 1. Here Γ is the differential energetic particle spectral index; Q_n is the total solar neutron production normalized to an ambient density of 1 hydrogen atom (or proton) cm^{-3} and 1 accelerated proton of energy greater than 30 MeV; and φ_n (20-200 MeV) is the calculated steady state flux of 20 to 200 MeV neutrons at earth. The results of Table 1 are based on an energetic particle composition which is taken to be the same as that of the ambient material, or H:He:CNO = 1:0.08:0.002[5].

It should be noted that the results of Table 1 are only weakly dependent on the spectral index Γ. This relative constancy is of considerable importance since both the spectra and intensities of accelerated particles stored at the sun during quiet-times are unknown. Since observations of solar particles at earth (J. Wang and M. Van Hollebeke, private communication) indicate average spectral indexes of about 3 to 4 (with important variations with time and composition), and because of the relative insensitivity of the results in

Table 1 to Γ, the range $2 \leq \Gamma \leq 5$ should cover all cases of interest. Note also that the ratios φ_n/Q_n to be used are independent of the ambient density and the total number of accelerated particles. The upper limit φ_n(20-200 MeV) $< 3 \times 10^{-4}$ neutrons $cm^{-2}sec^{-1}$ then implies that the total neutron production at the sun should be less than 3.5×10^{24} to 5.7×10^{24} neutrons sec^{-1} for Γ ranging from 2 to 5. These values are lower by a factor of 350 to 600 than the production rate of solar neutrons estimated by Lin et al.(1) as necessary to account for the observed electron excess at ~ 200 keV. The discrepancy factor between the required neutron production and calculated upper limits may be decreased by about 10 to 20 by replacing diffusive propagation of solar electrons, which Lin et al.(1) considered, with the maximum trapping in the inner solar system allowed by the expanding solar wind. (There is, however, no indication that trapping does in fact take place.) The maximum trapping time is of the order R/V, where R is the radius of the trapping volume and V is the solar wind speed. Since low-energy solar flare electrons are observed to undergo little scattering during propagation from the sun(6), the trapping boundary has to lie outside one A.U. The factor of 10 to 20 is obtained by using $R = 3 \times 10^{13}$ cm and $V = 4 \times 10^{7}$ cm sec^{-1}, a set of values which yields a required neutron production rate of 7×10^{25} neutrons sec^{-1}, as opposed to the value of 2×10^{27} neutrons sec^{-1} obtained by Lin et al.(1). We conclude that electrons from the decay of solar neutrons can produce at most 10% of the observed electron excess at 200 keV if we use the model of maximum trapping, but more likely they produce less than 0.3% if we use the diffusion model discussed by Lin et al.(1).

For the calculation of neutron production in interstellar space we use the same techniques as for solar neutrons. We consider the limiting cases of the cosmic ray spectrum: an intensity as observed near earth with a reasonable or minimum amount of solar demodulation, and a hypothetical low-energy component which increases with decreasing energy. We find that if the cosmic ray energy density in interstellar space does not exceed the maximum energy density as estimated from arguments based on the stability of the galactic disk, cosmic-ray produced neutrons can only account for ~ 0.2% of the required electron excess at ~ 200 keV. Because of this negative result, we shall not give the details of the derivation.

One final remark on the neutron source model concerns the shape of the expected electron differential spectrum. This is illustrated in Fig. 1 for neutrons at rest, along with the observed data and a ≈ 75 keV Maxwellian distribution, for comparison. As can be seen, the theoretical neutron decay curve does not have a shape which peaks exactly in the same energy region as the bump in the observed spectrum, but at a somewhat higher energy. This, however, is by itself not necessarily an argument against the neutron origin model, since the electrons may lose energy during their propagation; for example, if the neutrons are produced at the sun, adiabatic deceleration in the expanding solar wind[7] could yield the required energy loss. Nonetheless, since both solar and cosmic-ray produced neutrons are inadequate to account for the observed electron excess at ~ 200 keV, and because there are no other known astronomical sources of free neutrons, a neutron-decay origin of these electrons should probably be abandoned.

As is indicated in the figure, the observed spectral feature at 200 keV may be fitted instead by a Maxwellian distribution of effective temperature kT ≈ 75 keV. An astronomical object which might conceivably produce such an electron spectrum at earth is the x-ray source Sco X-1. The distance to

Sco X-1 has been directly estimated from its proper motion as $\sim$ 170 pc[8], although other estimates[9] indicate distances ranging from about 300 to 1000 pc. This source possibility should be at least examined in view of the coincidence between the observed interplanetary electron spectrum and the x- and gamma-ray observations of Sco X-1[10]. The x-ray emission consists of a thermal component with exponential spectrum of characteristic temperature $kT \sim 5$ keV, and another hard component which dominates the emission at energies greater than about 50 keV. The differential energy flux of the hard component may be characterized either by an exponential with 100 keV $< kT <$ 370 keV or by a power law with spectral index 0.8 ± 0.3 with an unknown high energy cutoff[10]. At a distance of 170 pc the luminosity at photon energies of 40 to 350 keV is $\sim 1.3 \times 10^{34}$ ergs/sec[10] while the luminosity of the thermal component at the same distance is $\sim 2 \times 10^{36}$ ergs/sec[9]. If the hard component is interpreted as bremsstrahlung of 40 to 350 keV electrons, it indicates the presence of such electrons at Sco X-1.

Let us assume now that some fraction of the < 300 keV electrons are ejected into interstellar space and that these electrons uniformly fill up a sphere around Sco X-1 with a radius of at least 200 pc, arbitrarily chosen so that the earth is inside this region. If the production rate of < 300 keV electrons at Sco X-1 has been constant over at least $\sim 2 \times 10^4$ years, a time equal to the lifetime against Coulomb collisions of $\sim$ 200 keV electrons in the interstellar gas with average density of 1 cm^{-3}, an equilibrium intensity of 0.8 $cm^{-2}sec^{-1}sr^{-1}$ in the spherical cavity of radius $\sim$ 200 pc requires an electron energy output at Sco X-1 of $\sim 1.2 \times 10^{35}$ ergs sec^{-1}. This value is larger than the observed luminosity of the hard component, but is much smaller than both the thermal luminosity of Sco X-1 and the power that would have to be supplied to the 40 to 350 keV electrons if x-rays in this energy range were produced by non-thermal bremsstrahlung. (Since the radiation yield of 350 keV electrons is $\sim 4 \times 10^{-4}$, this power is $\sim 3 \times 10^{37}$ ergs sec^{-1}.) Provided that the residual solar modulation at ~ 200 keV is not exceedingly large, Sco X-1 is energetically capable of producing the observed electron excess at earth. However, it is even possible that particles with small gyroradii are not modulated at all[11]; in this case, when ionization losses are taken into account, the observed hard x-ray spectrum of Sco X-1 would be consistent with the observed electron excess at ~ 200 keV.

Consider now an alternative interpretation to the observed electron spectrum. Figure 2 illustrates a model in which, instead of a bump or excess, the spectral feature at ~ 200 keV consists of a low-energy cutoff to a single power law with spectral index ~ 3, between about 200 keV and 2 MeV. This power-law interpretation may even provide a somewhat better fit to the data than does the bump or excess model. We consider here several non-solar possibilities for the source of electrons above ~ 100 keV since these electrons show none of the marked time variations characteristic of particles accelerated at the sun as do those below ~ 100 keV[1].

If the electrons are galactic in origin, the cutoff could be produced by collision losses which the electrons suffer during propagation through the interstellar medium. To have a power law with a cutoff at ~ 200 keV, the age of the source of the electrons must be $\sim 2 \times 10^4$ years. The supernova Vela X would be a reasonable candidate for this source since the age of the remnant of this supernova is about 1 to 2×10^4 years. Problems of charged particle propagation from Vela X have been previously discussed; it was shown that the age and distance to this object are consistent with it being a prolific source of cosmic rays over a wide energy range both in the Gum Nebula and near earth[12]. We should also consider that the cutoff may be the result of solar modulation, produced perhaps by scattering by magnetic field irregularities in the inner solar system.

It is also interesting to note that the spiral nature of the interplanetary magnetic field may result in a cutoff below which low-energy electrons (and nuclei) can not penetrate into the solar cavity. If the interplanetary field continues to execute the Archimedes spiral pattern out to, e.g. 50 A.U., then at this distance it will lie in essentially the azimuthal direction, making an acute angle $\psi = \tan^{-1}(50)$ with the heliocentric radial direction. Let us assume that the particles propagate freely along the mean field, but that there is sufficient diffusion due to field-line random walk in the polar direction to eliminate any gradients set up by the interplanetary electric field. (The diffusion coefficient in the polar direction, due to the random walk of field lines in the photosphere, supposedly increases in proportion to heliocentric distance[13].) Then, just as in discussions of the diurnal anisotropy[14], to maintain a steady-state, i.e. no net radial streaming, the streaming velocity of particles along the mean field, $u_{\parallel}$, must be $u_{\parallel} \simeq V \tan\psi$. With $V = 400$ km/sec and $\tan \psi = 50$, $u_{\parallel} = 2 \times 10^9$ cm/sec. Clearly, particles with a velocity parallel to the mean field that is less than $u_{\parallel}$ cannot penetrate into the solar cavity. However, this implies only that galactic electrons with energies less than a few keV (or protons with energies less than a few MeV) are excluded. In fact, even higher energy particles should have difficulty in penetrating into the solar cavity, since, unless their velocity is much larger than $u_{\parallel}$, the particle distribution function will be highly anisotropic and will be subject, presumably, to streaming instabilities[15]. These instabilities give rise to magnetic field irregularities which scatter and thus exclude the particles.

In order to produce the observed cutoff at ~ 150 keV, we require that only electrons with velocity $v > 10\ u_{\parallel}$ (corresponding to an anisotropy < 30%) may stream freely along the field. Note, however, that we do not treat the possibility that low energy electrons seen in the ecliptic plane might enter over the solar poles where the field does not execute a tight spiral pattern.

Finally, we mention that a solar wind shock transition at the boundary of the heliosphere might be an efficient accelerator of low energy particles giving rise to the electrons in the energy region of the observed spectral feature. (The cutoff could then be produced by the above modulation mechanism). For particles to be accelerated efficiently by a shock they must presumably remain in contact with the shock front for an extended time. One simple way to accomplish this is to have the magnetic field nearly aligned with the shock front, which may indeed be the situation at the shock at the heliosphere boundary.

In summary, we have discussed two interpretations of a feature in the recently observed spectrum of interplanetary electrons in the vicinity of ~ 200 keV. This spectral feature could be interpreted as a bump or excess above a continuum or as a low energy cutoff to a power law; the data being insufficient to uniquely distinguish between these possibilities. We have shown that the electron excess of ~ 0.8 electrons $cm^{-2}sec^{-1}sr^{-1}$ at ~ 200 keV cannot result from neutron decay, because neutron production in both the solar atmosphere and in interstellar space is insufficient to account for the observed electron intensity and no other known astronomical sources of free neutrons are available. A model in which the bump at ~ 200 keV is produced by the nearby X-ray object Sco X-1 is also considered and is found not to be inconsistent with the data.

As an alternative interpretation of the spectrum of interplanetary electrons in the 100 keV to 2 MeV region, we have proposed that they are of nonsolar origin and that their spectrum can be fitted by a single power law with a low-energy cutoff. This cutoff could be produced by either of at least two possible mechanisms: collision losses in interstellar space or propagation along an interplanetary magnetic field which is essentially perpendicular to the heliocentric radial direction at large distances from the Sun. The power law itself could be due to a young galactic source (e.g. Vela X) or acceleration at the shock transition at the boundary of the heliosphere.

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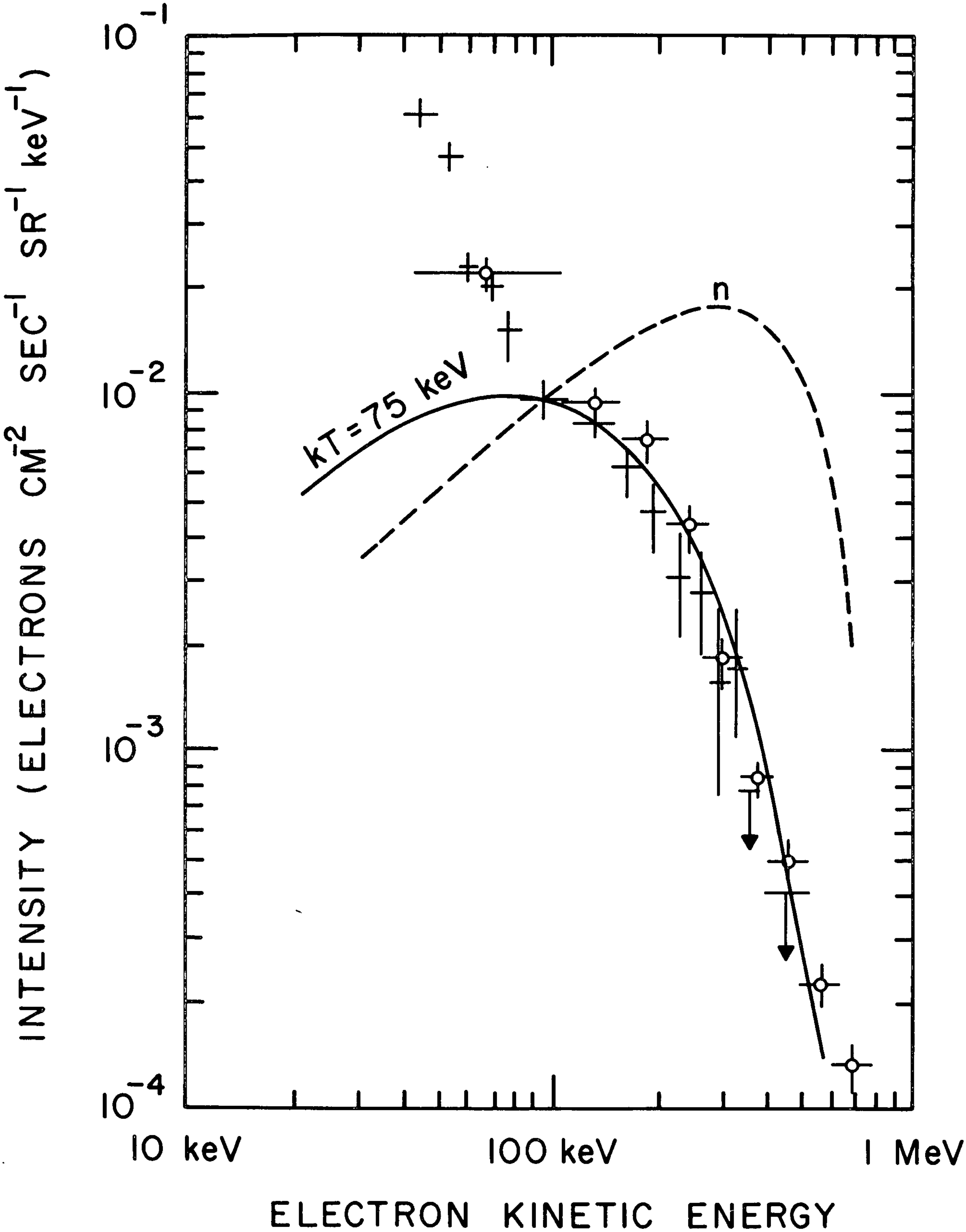
TABLE 1. Neutron fluxes at earth and total production rates at the Sun.

Γ	$\frac{\varphi_n(20\text{-}200\ \text{MeV})}{Q_n}(\text{cm}^{-2})$	$Q_n(\frac{\text{neutrons}}{\text{sec}})$
2	$.86 \times 10^{-28}$	1.3×10^{-16}
3	$.85 \times 10^{-28}$	$.84 \times 10^{-16}$
4	$.67 \times 10^{-28}$	$.72 \times 10^{-16}$
5	$.53 \times 10^{-28}$	$.7 \times 10^{-16}$

Figure Captions

1. Electron spectra in the vicinity of the spectral feature at ~ 200 keV. Data points - observed spectrum(1); solid line - Maxwell-Bolzmann distribution; dashed line - neutron-decay electrons. Both calculated curves are normalized to the data at 100 keV.

2. Quiet-time electron spectra from a few tens of keV to about 20 MeV(1). Solid line - proposed fit to the 100 keV to 2 MeV data.



INTENSITY (ELECTRONS CM^{-2} SEC^{-1} SR^{-1} keV^{-1})
10^{-1}
10^{-2}
10^{-3}
10^{-4}
n
kT = 75 keV
10 keV
100 keV
1 MeV
ELECTRON KINETIC ENERGY

FIGURE 1

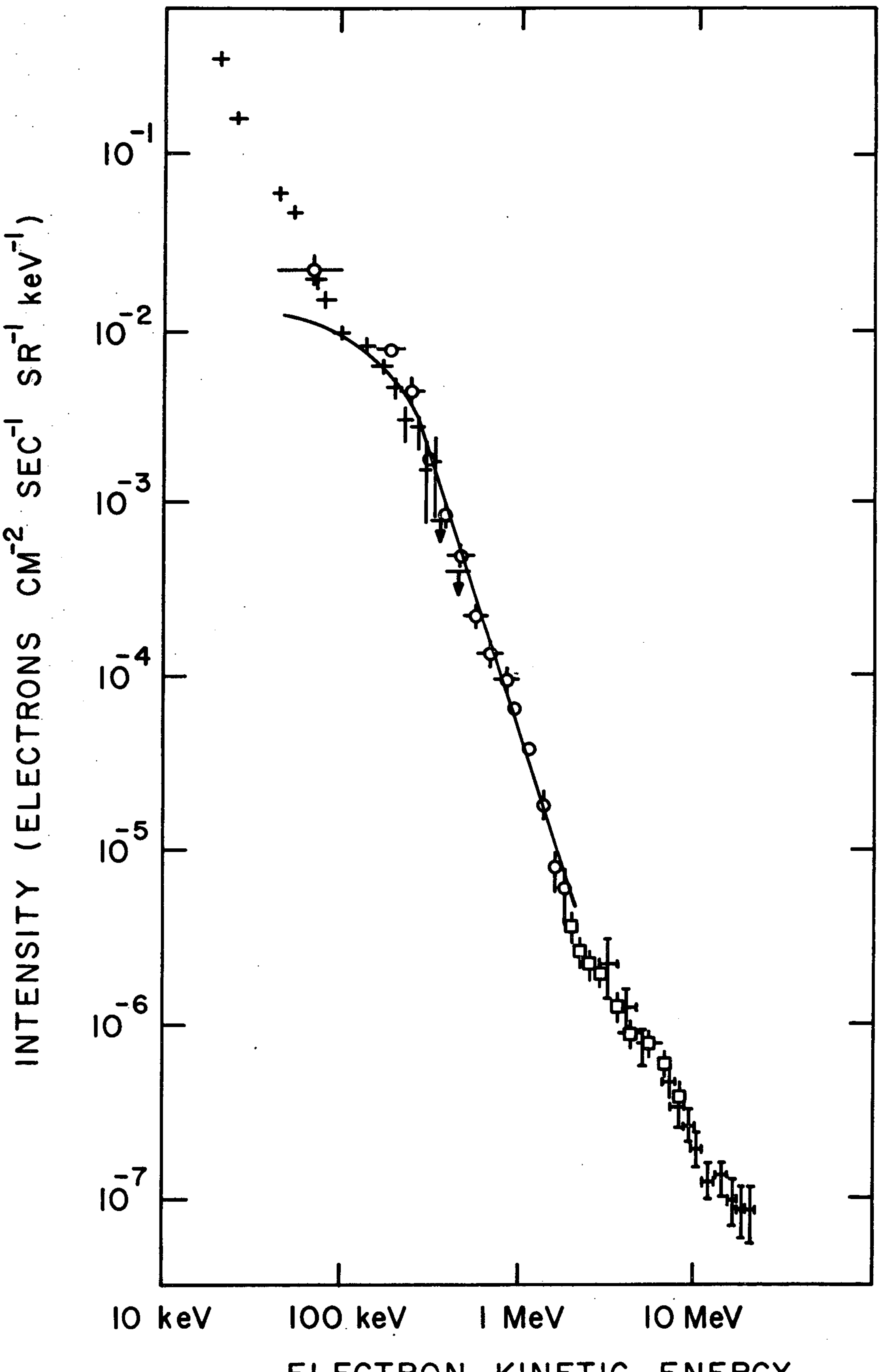


FIGURE 2

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